ENVIRONMENTAL PROTECTION BY APPLICATION OF THE STG CLAY-BASED GROUTING METHOD IN MINING AND CIVIL ENGINEERING

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ABSTRACT

The paper deals with a complex approach to the solution of the present-day problems of environmental protection by application of the STG Clay-based Grouting Method.
New technologies and case histories of protection of aquifers from contamination and depletion, the localisation (grouting) of acid mine water flows to prevent their migration into surface and subsurface water basins, protection of ground surface from subsidence and atmosphere from dry tailings by guaranteed filling of underground voids with unshrinking grouts formulated on the basis of such tailings are presented.

INTRODUCTION

Interaction of man with nature has a dual character. From one side, man can not exist without natural resources, from the other side, he actively reconstructs nature. To improve the efficiency of environmental protection STG has developed the following technologies:

- Protection of aquifers from depletion and wastes pollution.
- Protection of ground surface from subsidence, deformation and contamination.
- Protection of atmosphere from products of combustion of waste dump and dry tailings fouling.

Below are presented above enumerated technologies and some case histories of their application.

PROTECTION OF AQUIFERS BY STG GROUTING METHOD

The range of environmental problems which can be resolved by grouting technique will be limited still such a solution involves obvious advantages.

First, by creating a sealing (grout) cover we attain what may be called the localisation of mining activities zone from natural water bearing complex providing minimum impact on regional hydrodynamic balance. Moreover, if one employs the use of a chemically inert material there will be practically no pollution of ground water caused by the processes of diffusion exchange and leaching. STG experience shows that stabilised grouts formulated on the basis of clay slurries and fine-dispersion pulps become the optimum material in most cases (ready to meet also the requirements of workability and cost parameters).

Second, on the completion of grout cover formation surplus expenditures on further "maintenance" of this underground structure are eliminated.

Finally, flexible application of the principle to develop grout formulation for each particular case can assist in effective solution of problem associated with the utilisation of ore processing wastes especially while undertaking large-scale projects.

To improve the protection of aquifers STG has developed the following technologies described in Table 1.

The techniques of aquifers protection	The point of techniques
1. Protection of underground aquifers from depletion	By STG Clay-based Grouting Method as an alternative to dewatering and mine drainage under complex hydrogeological conditions during vertical shaft sinking and driving horizontal and inclined underground openings
2. Protection of surface and subsurface water basins from acid mine water contamination	By localisation of acid mine water flows to prevent their migration into surface and subsurface water basins using STG grouting method
3. Protection of underground aquifers, surface basins and rivers from chemical and toxic wastes	By localising tailings ponds and disposed wastes with sealing by clay-based grout covers with required depth, thickness, shape and size
4. Protection of surface water basins from depletion	By watersealing of permeable soil which holds surface water basins using clay-based grout
5. Protection of underground waters and rivers from seepage of radioactive waste	By creation of clay-based grout encasement around and under tanks and storage with radioactive wastes

Table 1. List of techniques of aquifers protection by the STG Grouting Method.

CASE HISTORIES OF AQUIFERS PROTECTION

Protection of aquifers from depletion

Commissioning and production life of mining enterprises involve intensive discharge of ground water through operating drainage and disposal systems with the formation of industrial wastes basins. This results in considerable changes of hydrodynamic and chemical regimes of adjacent regions that, as a rule, will case depletion of groundwater resources and deterioration of its sanitary indexes.

To provide the protection of ground water from depletion, the sinking of mine shafts in the Former Soviet Union and some other ore and coal mining regions in the Eastern Europe Block counties are carried out employing the use of grout covers by STG Method. Such grout covers are preliminary formed in fractured or karst aquifers or abandoned workings within the total depth of future shafts through directional holes drilled from ground surface. Such practice eliminated the need to perform dewatering by maintaining depression cones.

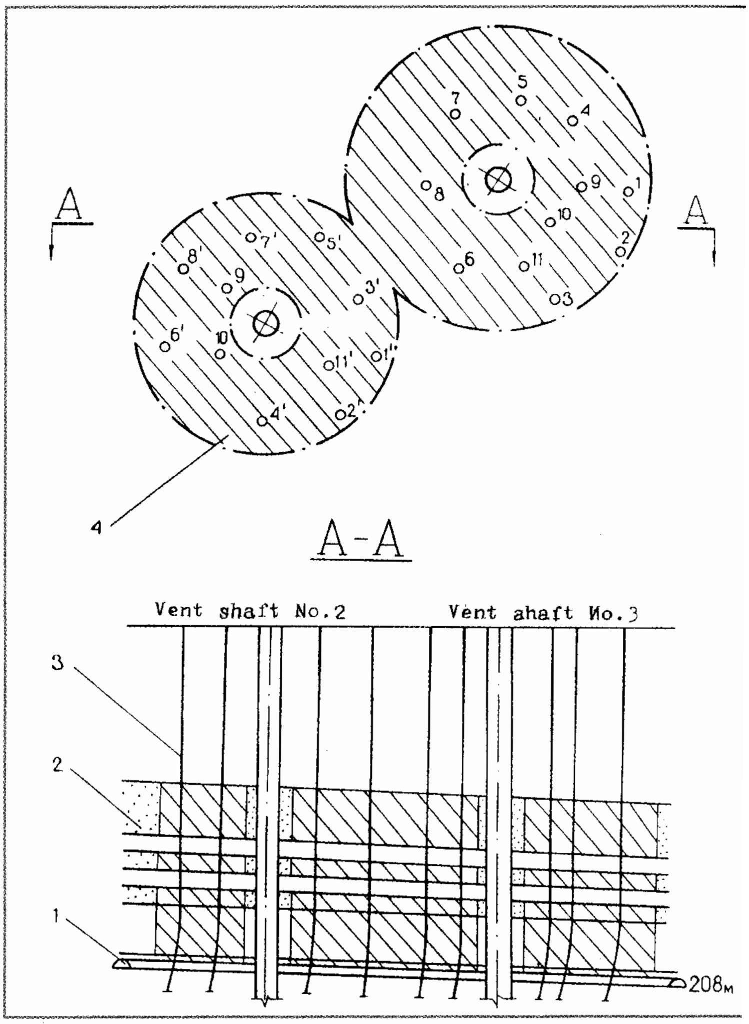
For example, the sinking of two shafts of the Yuzhnaya Mine in Russia through water-logged abandoned workings (Figure 1) had been first planned with high-capacity pumping. With the objective to cut down the cost of pumping and preserve the natural balance of ground water the project report was revised to design a STG pregrouting program. Shaft sinking is now completed with the natural hydrodynamic balance maintained.

Large water bearing fault zones discharging inflows up to 2000 cu. m per hour are often encountered during frivage of major workings. Dewatering of such zones will destabilise the regional hydrodynamic regime and result in increased mineralization of surface water reservoirs. To enable safe intersection of large fault zones there has been developed an innovative technique to pregrout the faults leaving all grouting equipment on the ground surface.

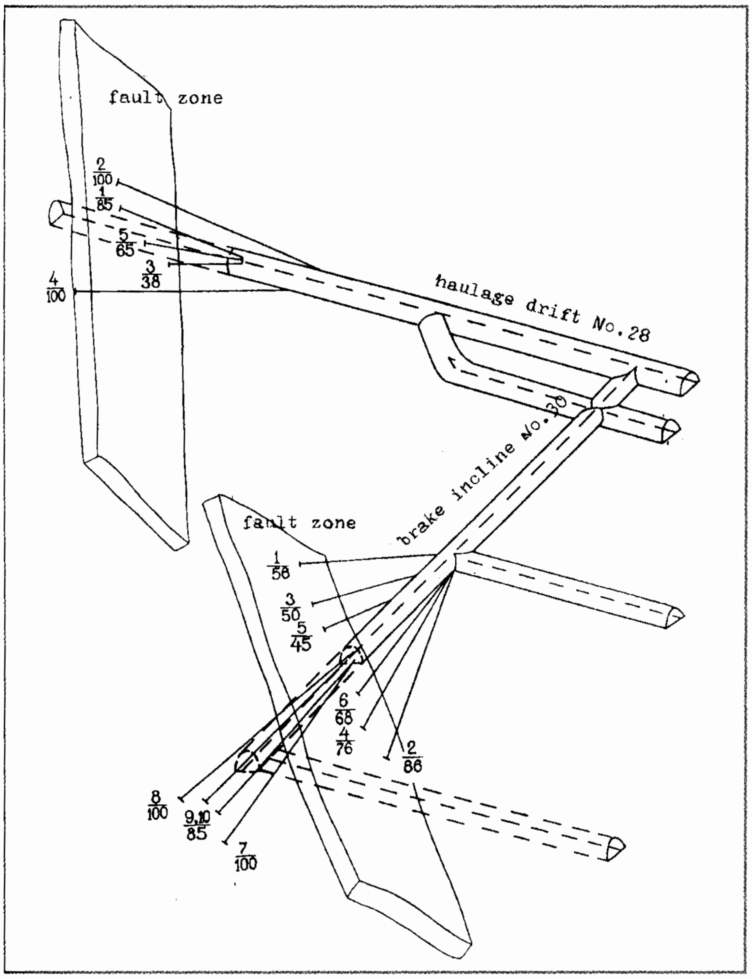
At one of the mines in Donbass area, Ukraine a haulage drift was driven using pumping for water control. However, three years of pumping more than 5 mln. cu m of water resulted in the reduction of inflow from 200 cu. m/hr to only 100 cu. m/hr. Further activities were continued on the basis of grouting program designed by the STG Agency (Figure 2) on the completion of which the drivage operations were successfully finalised.

Protection of aquifers from acid mine water contamination

The objective of the first STG clay-based grouting demonstration project in the United States, funded jointly by DOE and EPA, was to reduce the inflow of shallow groundwater and surface water through the Mike Horse fault system and into the abandoned underground workings of the Mije Horse Mine.



1.- Water logged abandoned workings, 2.- Water bearing strata, 3.- Grout holes, 4.- Grout co
Figure 1. Grouting procedure for abandoned workings around mine shafts of the Yuzhanaya Mine.



8/100 – Number and depth of grout holes.
Figure 2. Pregrouting procedure in driving development workings.

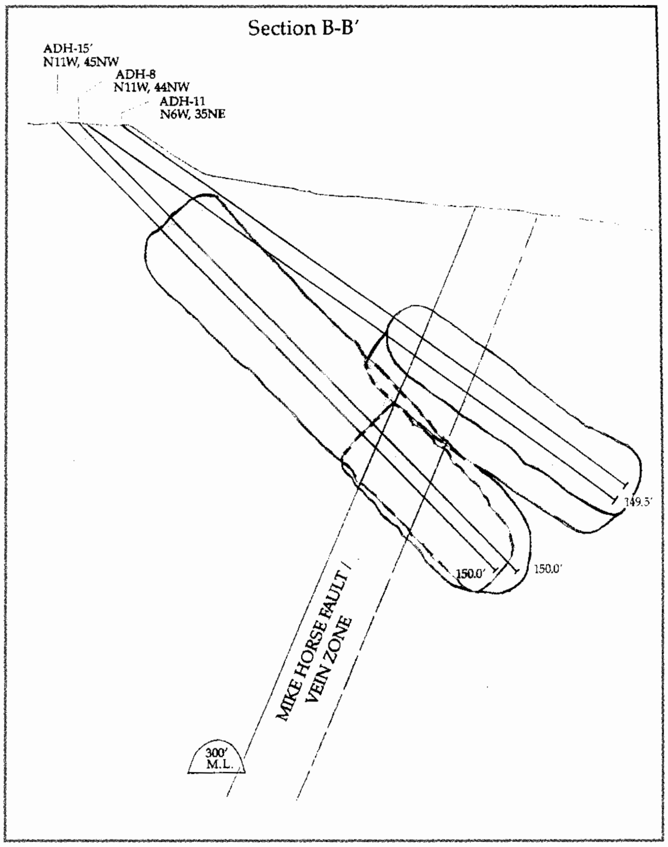


Figure 3. Schematic showing the creation of the grout curtain though angled grout holes.

Acid rock drainage from the portal of the mine was reduced as result of grouting. The pH of the discharge was 3.5. The owners of the Mike Horse Mine, (ASARCO and ARCO), have permitted STG clay-based grouting demonstration at the site under the Mine Waste Treatment Pilot Program.

To accomplish this purpose, clay-based grout is being injected into the underlying bedrock and alluvium through two rows of inclined holes drilled from the surface. Injection is being performed in the fall of 1994.

Four investigation angle holes were drilled, and packer tests were performed to determine pregrout conditions prior to commencement of actual work.

The first phase consisted of drilling and grout injection through two rows of inclined grout holes, Figure 3. The angle of five grout holes was 35 degrees (from horizontal), and the angle of the remaining holes varied from 45 to 67 degrees (from horizontal). The length of the holes varied from 45 to 50 meters. The diameter of surface casings was 108 mm, and the diameter of boreholes was 76 mm. The grout was injected through a packer in order to control pressures and in stages to control grout dispersion.

During thirty working days, excluding packer testing, mobilisation and demobilisation, a total of 1195 cubic meters of STG clay-based grout was injected in the lower half of the grout holes. The average placement rate was 40 cubic meters per day and was done primarily during a single-shift operation. Immediate ramifications were observed when the water level rose in monitoring wells. The largest increase was in MW-6 which rose from 63.45 meters to 8.00 meters. The effects of grouting on streamflow, water levels in monitoring wells, and portal discharge are being monitored continuously.

The Mike Horse Mine site, located approximately 15 miles east of the town of Lincoln, Montana, USA, is in the inactive Heddlestone Mining District and has been recognised as a contributor to the pollution problems associated with the upper Blackfoot River ecosystem which includes Mike Horse Creek.

The Mike Horse Creek is the major drainage feature in the project area. Historic data indicate that acid rock drainage and heavy metal-laden sediment from the portal discharge are being released into Mike Horse Creek. The upper reach of Mike Horse Creek loses flow into the subsurface strata in the area where the stream crosses the Mike Horse vein/fault system. The mine workings generally follow the vein/fault system, which was a lead-zinc producing ore body. This area was designated for demonstration of the STG clay-based grouting technology. Grouting in the vein/fault system inhibited groundwater from entering the mine workings and reduce the volume of acid rock drainage from the 300-level portal.

A high hydraulic conductivity of fault zone was encountered, and injection was limited by the pump capacity of 4.1 MPa. Results of grout injection into angled holes (35 degrees from horizontal) of the first row are presented in Table 2.

Grouting intervals along holes, m	Total volume of grout pumped in holes, m^3				
	Holes				
	ADH-6	ADH-7	ADH-9	ADH-11	ADH-17
40-45	4	143	72	9	28
35-40	2	26	6	8	32
30-35	15	25	11	99	12
20-30	-	25	-	-	-
10-20	-	92	-	-	-

Table 2. Results of grout injection through angled holes (35 degrees from horizontal).

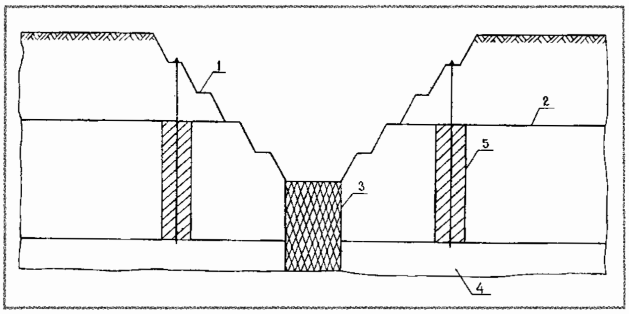
Results of grout injection into angled holes (45 degrees from horizontal) of the second row are presented in Table 3.

Grouting intervals along holes, m	Total volume of grout pumped in holes, m^3					
	Holes					
	ADH-8	ADH-13	ADH-14	ADH-15	ADH-15'	ADH-16
45-50	43	58	193	10	39	11
40-45	51	21	80	-	53	5
35-40	42	36	18	-	-	16
30-35	3	4	-	-	-	-

Table 3. Results of grout injection into angled holes (45 degrees from horizontal).

The preliminary calculated coefficient of anisotropy is 0.6. The radius of grout dispersion in the direction of the main fracture system, computed by the permeability of water bearing rock and the pressure of injection, ranged from 2 - 3 meters to 9 - 10 meters, as presented in Table 4.

grout mixtures. Their formulations include clay suspensions and processing plants slimes, additives of special reagents and setting agents. At present the implementation of one such project is in termination. Preliminary estimates show that water control by grouting technique will be four times cheaper than the construction of a dewatering system. This scheme resolves also the problem of environmental protection and further development by underground mining (Figure 4).



1.- Opencast bench, 2.- Water bearing zone, 3.- Ore body, 4.- Water resisting strata, 5.- Sealing curtain.
Figure 4. Arrangement of sealing curtain around an opencast.

PROTECTION OF GROUND SURFACE

While assessing the potential of grouting technique in solving the environmental problem it is necessary to state the following. As it is known, ground treatment by grouting can be applied for sealing off underground excavations, consolidation of rock strata and filling karst or mined-out zones. During

Radius of grout dispersion, m	Grout Holes										
	ADH-6	ADH-7	ADH-8	ADH-9	ADH-11	ADH-13	ADH-14	ADH-15	ADH-15'	ADH-16	ADH-17
	2-4	9-10	5-6	7-8	2-3	4-5	9-10	2-3	4-5	3-4	4-5

Table 4. Radius of grout dispersion in the direction of the main fracture system.

Protection of aquifer from saline water

Development of some kimberlite deposits in Yakutia area, former USSR, in permafrost strata is complicated due to occurrence of highly saline ground water wish does not freeze even under rock temperature up to minus 3 °C.

The occurrence of thick artesian brine aquifers and ecological problems associated with this preclude from the application of conventional water control techniques for opencasting. Under such condition dewatering, for example, will be not effective since preliminary of brines involves the construction of costly and laborious installations.

Feasibility studies into this field proved the effectiveness of sealing covers around such type of deposits using the emplacement of STG low-temperature stabilised or freezing

planning and implementation of grouting programs technical capabilities to predict accurately geometry and spacing of sealing covers, and control the processes of their formation can enable an engineer to adopt simultaneous application of a grouting scheme for the protection of environment. The essence of engineering solution in this will be the formation of interlocked or barrier covers in permeable or water bearing layers in creating consolidated rock zones by grout injection treatment.

Research and feasibility programs into this field accomplished by the STG Agency and their wide industrial application enable us at present to provide the following technologies in ground surface protection described in Table 5.

The techniques of ground surface protection	The point of techniques
1. Protection of ground surface from subsidence in zone of abandoned underground works, karst zones and cavities below apartment houses and industrial sites	By guaranteed filling of underground openings, karsts and voids with unshrinking grouts formulated on the basis of loam and processing tailings using STG Grouting Method
2. Protection of ground surface from deformation below foundations of apartment houses and buildings at the sites of subway construction	By consolidation grouting of unstable soil under foundation of apartment houses and buildings
3. Protection of ground surface from contamination near tailing ponds and slime tanks	By watersealing of dams and embankments in soil, karst, fractured and tectonically broken rocks using clay-based grout
4. Protection of ground surface from subsidence in zone of excavation of inclined shafts	By Stabilisation and hardening of unstable soil above operated and constructed inclined shafts
5. Protection of ground surface from underworking in zones of mining extraction of mineral resources	By full stowing with unshrinking grouts formulated on the basis of processing tailings followed by the advance of working face using STG Grouting Method

Table 5. List of techniques of ground surface protection by the STG Grouting Method.

CASE HISTORIES OF GROUND SURFACE PROTECTION

Protection of ground surface from subsidence

Special grouts and process patterns to meet the conditions of high mineralization and magnesian aggression of ground water were used during the restoration of workings inundated by ground water brines in the property of Stebnick Potash Plant, Western Ukraine (Figure 5). The inrush of brine with a discharge of 2000 cu. m per day into two chambers of the 140 m level resulted in intensified karstification processes which lead to ground subsidence with the formation of 15 m diameter sink holes. Further increase in brine discharge and karst formation endangered the existence of the mine.

To seal off the inrush of ground water and stop further subsidence, there were drilled several series of grouting holes at a depth from 75 m to 140 m through which the designed quantity of special grout was injected. As a result, the situation was normalised, mining operations were resumed and ground subsidence completely stopped.

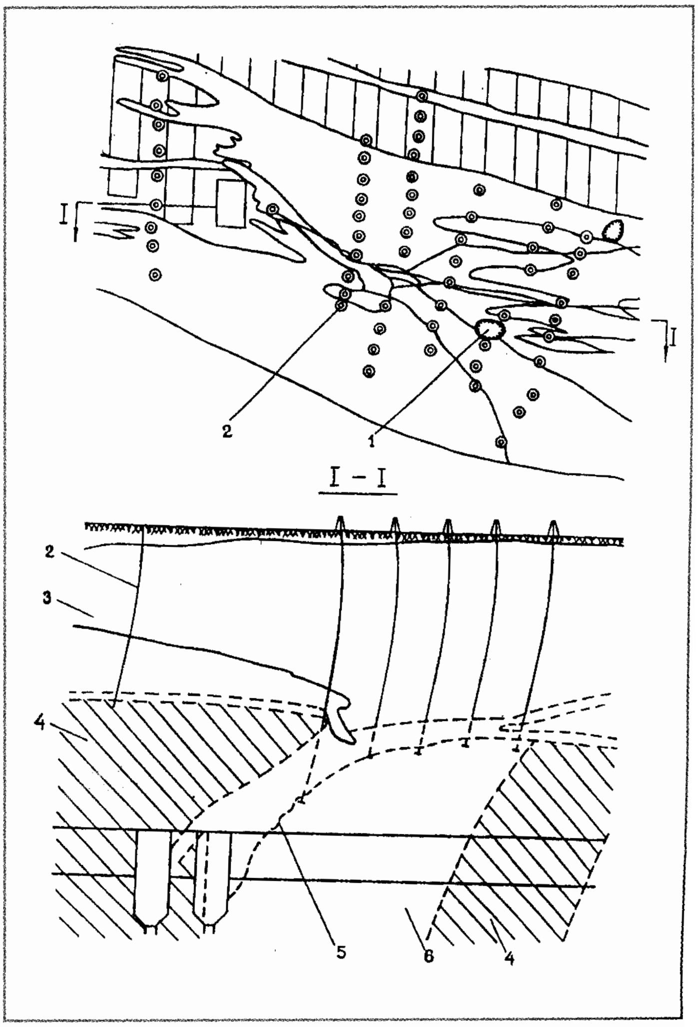


Figure 5. Grouting scheme used during restoration of productive chambers at Stebnik Potash Plant.

Protection of ground surface from deformation and ravine erosion

To protect farming lands from ravine erosion, the STG Agency has developed and introduced at several projects in the Moscow-Region Coal Basin a technique for the prevention of quick sand inrushes into mine openings that had been accompanied by rock strata deformation, ground subsidence and formation of a system of ravines spoiling farming areas.

During drivage of the eastern branch of the shaft insets at the 70 m level of the Belkovskaya Mine the inrush of water-sand-clay mass with a discharge of 180 cu. m per hour occu-

The techniques of atmosphere protection	The point of the techniques
1. Protection of atmosphere from products of combination of waste dump	By localisation and fire suppression of underground nucleation site for combustion of waste dump using injection of thermally stable grout through drillholes
2. Protection of atmosphere from her pollution by fly-ash and dry tailings	Full stowing of opening of closing mines and zones of mining extraction with unshrinking grouts formulated on the basis of fly-ash and tailings
3 Protection of atmosphere from her contamination by waste dump	Processing of waste dumps and extraction of mineral resources and of raw for building materials

Table 6. List of techniques of atmosphere protection by the STG Grouting Method.

rred. It resulted in the outflow of more than 5000 cu. m of water saturated material into the mine workings. The grouting scheme comprised ground treatment through holes drilled into the overlying layer. Grouting holes were interesting the voids from 2.5 to 6.2 m height. Grout composition was formulated on the basis of local loams. Prior to the commencement of grout emplacement interhole acoustic sounding had been conducted to determine the boundaries of voids propagation. On the completion of grouting program the drivage operations were resumed.

PROTECTION OF EARTH ATMOSPHERE

To improve the atmosphere protection STG has developed the following technologies described in Table 6.

CASE HISTORIES OF EARTH ATMOSPHERE PROTECTION

The aim of the first clay-based grouting project in Poland was to protect the Earth atmosphere from products of combustion of waste dump of coal mine Matylda in Walbrzych. This project began in December of 1994 and was completed in July 1995 by drilling 194 bore holes with depth 26 meters each around the underground combustion sites. Through this boreholes of 4108 cubic meters of clay based grout were injected.

As a result the surface temperature of waste dump decreased from 65-70 °C to 20-25 °C.

All above enumerated drilling and grouting works at coal mine Matylda were performed by Polish PRGW Company with STG assistance.

To protect the atmosphere from the pollution by fly-ash and dry tailings STG began full stowing of underground working of closing mines in Ukraine with unshrinking grouts formulated on the basis of fly-ash and tailings.

CONCLUSIONS

The problems of environmental protection are characterised by complexity and multiplicity of aspects. Naturally, their effective solution will require further programs of feasibility studies and research into the field of accurate forecasting and control proceeding dealing with technological impact on nature.

Taking account of this the application of specialist techniques with an objective to simultaneously provide environmental protection measures seems to be a rational approach efficiency and advantages of which can be proved by successful experience in the employment of STG Grouting Method.